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STREAM CHEMISTRY FOLLOWING A FOREST FIRE
AND UREA FERTILIZATION
IN NORTH-CENTRAL WASHINGTON

by

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ABSTRACT

During 2 years of study, nitrate-N in streamflow increased from background levels of 0.005 part per million (p.p.m.) in a control stream to 0.042 and 0.310 p.p.m. in streams from burned and burned, urea-fertilized watersheds, respectively.

Cation concentration increased on the burned, unfertilized watershed, but because of dilution effects, decreased to levels of the control stream on the burned, fertilized watershed.

Neither burning nor urea fertilization caused increases in nitrogenous constituents to levels above those recommended for municipal water supplies. Concentrations of nitrate-N observed indicate that losses of N in this form will have a negligible effect on future productivity of these forest ecosystems.

Keywords: Streams, forest fire effects, fertilization (plants), urea.

INTRODUCTION

During July 1970, 6,400 hectares (1 ha. = 2.47 acres) of forested land on the north edge of Lake Chelan west of Chelan, Washington, were burned by an intense wildfire. After the fire, a U.S. Forest Service rehabilitation team recommended that the burned areas be seeded with grasses and legumes and fertilized with urea to help prevent soil erosion and restore plant-soil nutrient cycles.

Urea is an organic nitrogen fertilizer that hydrolyzes to ammonium carbonate and may be converted eventually to nitrate-N in the soil. The addition of large quantities of urea as fertilizer to the soil thus serves as a potential supply of both ammonia-N and nitrate-N in streamflow, as snowmelt moves these nutrient ions into and through the soil profile. The application of urea to burned areas is of particular concern because soil-plant nutrient cycles have been temporarily severed. Without vegetation to utilize added nitrogen, the potential for movement of nitrogen ions from the soil profile into streamflow is greater than in an undisturbed forest. Since streams draining the area are a source of municipal water, the U.S. Forest Service, administrator of these lands, was concerned that nitrate-N and ammonia-N might exceed the proposed permissible limits of 10 and 0.5 p.p.m. (parts per million), respectively (Federal Water Pollution Control Administration 1970) and render the water unsafe.

This study was initiated in response to a request by the U.S. Forest Service administration to assess the impact of urea fertilizer on the chemistry of water flowing from the burned area.

THE STUDY AREA

Several large watersheds affected by the fire are located in T. 30 N., R. 20 and 21 E., Willamette meridian, on the north side of Lake Chelan. Topography is steep, with deeply incised slopes ranging from 30 to 100 percent. Elevation ranges from 360 m. (meters) at Lake Chelan to 2,400 m. (1 m. = 3.28 feet) at the crest of Sawtooth Ridge.

Prefire vegetation below 900 m. was characterized by scattered ponderosa pine (*Pinus ponderosa* Laws.), with an understory of bitterbrush (*Purshia tridentata* (Pursh) DC.), bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Sm.), cheatgrass (*Bromus tectorum* L.), and arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.). At intermediate elevations (900 to 1,800 m.) Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and ponderosa pine shared the overstory. Pinegrass (*Calamagrostis rubescens* Buckl.), Ross sedge (*Carex rossii* Boott), snowbrush ceanothus (*Ceanothus velutinus* Dougl.), alder (*Alnus sinuata* (Reg.) Rydb.), and willow (*Salix* spp.) were ubiquitous in the understory. Above 1,800 m., overstory consisted primarily of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and whitebark pine (*Pinus albicaulis* Engelm.). Prominent understory plants were Ross sedge, princes pine (*Chimaphila umbellata* (L.) Bart.), and whortleberry (*Vaccinium* spp.).

Soils are quite variable across the three watersheds but in general, well-drained, developing in coarse ash or fine pumice deposits overlying granitic or schist bedrock to depths of 3 m., or more.[1]

Precipitation ranges from 76 centimeters (1 cm. = 2.54 inches) at Lake Chelan to 100 cm. at the upper elevations, occurring mostly as snow. Minimum monthly mean temperature is -4° C. in January with a mean monthly maximum during July and August of 18° C.

METHODS

Because burning itself may exert an influence on stream chemistry, it was necessary to separate this effect from that of urea fertilization. To account for changes in water chemistry caused by burning only, an unburned and unfertilized watershed, a burned and unfertilized watershed, and a burned and fertilized watershed were sampled. A basic assumption to the study was that water chemistry of all three streams was similar before the fire.

The selected streams were: Grade Creek--unburned, unfertilized (control), 2,800 ha.; Camas Creek-- burned, unfertilized, 680 ha.; Falls Creek--burned, fertilized, 2,500 ha.

The two burned watersheds (Camas and Falls Creeks) were seeded by fixed-wing aircraft in October 1970 with 9.5 kilograms

per hectare (1 kg./ha. = 0.89 lb./acre) of hard fescue (*Festuca ovina* L. var. *duriuscula*), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), orchardgrass (*Dactylis glomerata* L.), and yellow sweetclover (*Melilotus officinalis* (L.) Lam.). Falls Creek was fertilized by fixed-wing aircraft October 19-21, 1970, with 78 kg./ha. of urea.

Between September 17, 1970, and July 20, 1972, 21 water samples were collected in plastic jugs at the mouth of each stream. Samples were taken at monthly intervals during fall and summer, and at biweekly and bimonthly intervals during spring and winter between September 1970 and September 1971. Sampling was discontinued between September 1971 and January 1972, then was reinstated at approximately monthly intervals until July 1972. Samples were collected from a free-falling portion of each stream, cooled with ice during transit, and stored at 3° C. No preservatives were added.

Samples were analyzed in the laboratory for pH, total alkalinity, and electrical conductivity using procedures described by Golterman and Clymo (1969) and Hem (1970).

Ionic and elemental constituents measured were: nitrate-N by cadmium reduction (Wood et al. 1967); urea-N by diacetyl monoxime (Beale and Croft 1961, Newell et al. 1967); ammonia-N by the phenolhypochlorite reaction (Weatherburn 1967, Sagi 1969); total organic N by Kjeldahl digestion (Chapman and Pratt 1961) with phenol-hypochlorite determination of ammonia; Ca, Mg, K, and Na by atomic absorption

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[1] Soil survey report by U.S. Forest Service Region 6 personnel, Portland, Oregon (unpublished).

spectroscopy (Robinson 1966). The detection limit for nitrogenous constituents was 0.001 p.p.m. Detection limits for cations were 0.1, 0.01, 0.03, and 0.03 p.p.m. for Ca, Mg, Na, and K, respectively.

RESULTS AND DISCUSSION

Nitrogen

Levels of nitrogenous constituents observed during the sample period in Grade Creek, the unburned, unfertilized control stream, showed that water from undisturbed forested ecosystems of this area is extremely low in these compounds. Total organic N in the control stream fluctuated widely between 0 and 0.089 p.p.m. and averaged 0.046 p.p.m. (1 p.p.m. = 1 milligram per liter). Nitrate-N levels in the control stream were very minute during the entire sample period, ranging from 0 to 0.016 p.p.m. (fig. 1). On most sample dates, the nitrate-N concentration was less than 0.002 p.p.m. Urea-N was found in the control stream on one date--in May 1972, 0.450 p.p.m. was detected. This most likely resulted from animal activity (urination) in the stream. Ammonia-N, ranging in concentration from 0.001 to 0.011 p.p.m., was detected on four sample dates between March and July 1972 in the control stream. Nitrite-N was not observed in any stream during the period of study. Levels of nitrate-N and other nitrogenous constituents observed in the control stream support the results of other workers (Johnson and Needham 1966, Fredriksen 1971, Moore 1971, Malueg et al. 1972), which indicate that nitrogen losses from undisturbed forested ecosystems are negligible.

The level of total organic N in Camas Creek (burned, unfertilized) was consistently above that of the control stream, ranging from 0.013 to 0.164 p.p.m., with an average of 0.109 p.p.m. Nitrate-N levels in Camas Creek were at the same level as in the control during the 1970-71 sample period, but there was an increase from background levels to 0.042 p.p.m. in March 1972. Except for the occurrence of 0.006 p.p.m. of urea-N in Camas Creek on October 23, 1970, urea-N and ammonia-N concentrations were at the same level as in the control stream. Drift of urea during fertilization of adjacent Falls Creek probably caused the increase in urea-N in Camas Creek.

Although the change was not as great in the present study, the behavior of nitrate-N after burning followed a pattern similar to that observed by Fredriksen (1971). He found that mean annual nitrate-N concentration in streamflow increased from less than 0.004 p.p.m. on a control watershed to 0.05 and 0.20 p.p.m. during the first and second years, respectively, after slash was burned on a clearcut watershed.

In Falls Creek, the stream from the watershed that was fertilized with 78 kg./ha. of urea after burning, there were increases in concentrations of urea-N and nitrate-N. Total organic N and ammonia-N remained at the same concentration as in the control stream. Urea-N was observed on four sample dates in the stream from the burned, fertilized watershed. Detection of 0.029 p.p.m. of urea on October 23, 1970, can
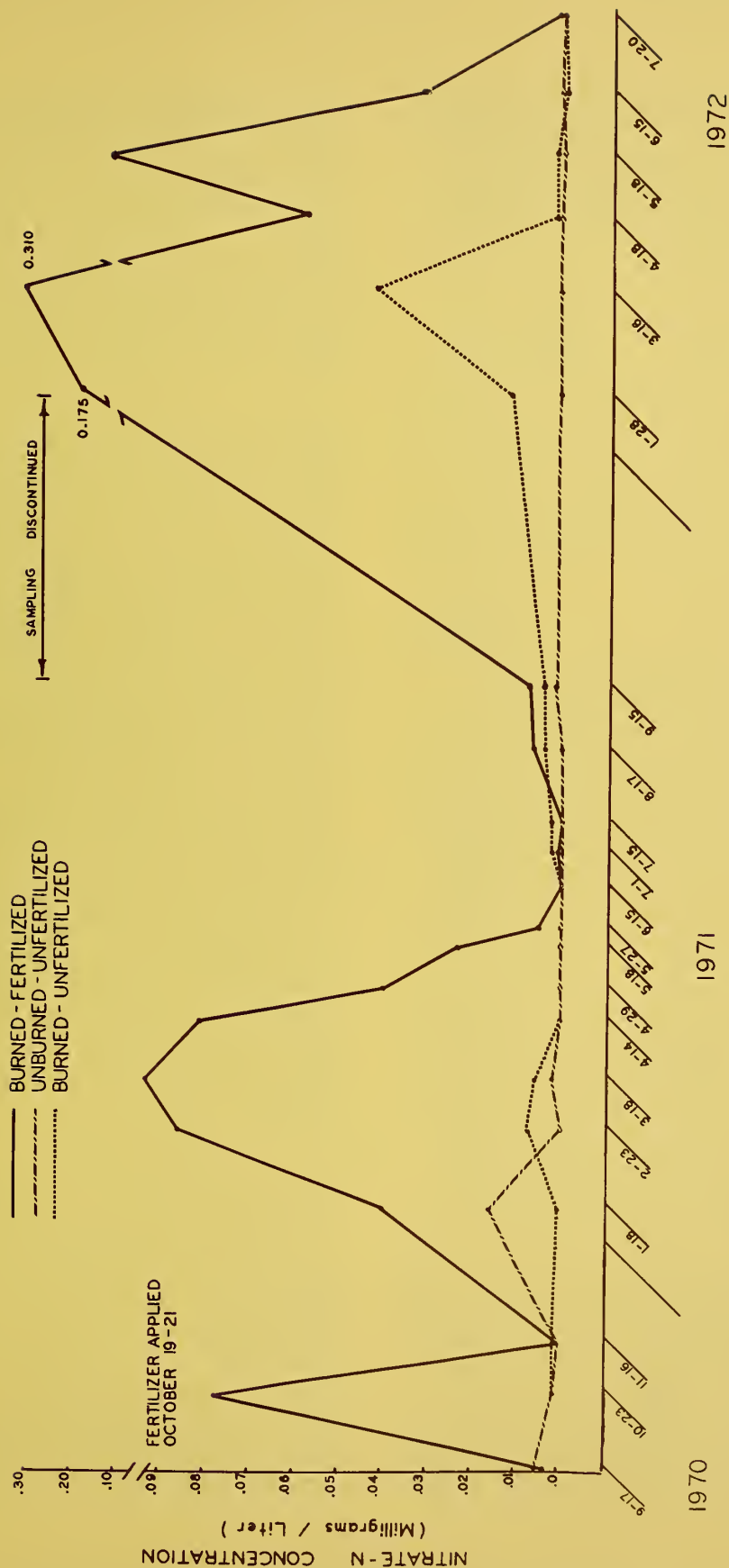
Figure 1.--Concentration of nitrate-N in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.

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be directly related to the fertilizer application; but occurrence of urea on the other three dates probably resulted from animal activity. The largest concentration observed was 0.330 p.p.m. in April 1972.

The response of nitrate-N concentration to urea fertilization after burning was a distinct contrast to the behavior of other nitrogen species. Fluctuations of nitrate-N in the stream from the burned, fertilized watershed were manifested by four distinct peaks that were not observed in the control stream (fig. 1). Concentration of nitrate-N increased from less than 0.005 p.p.m. on the first sample date to 0.077 p.p.m. on October 23, 1970 (2 days after fertilization). Concentration then dropped below detection limits (0.001 p.p.m.) by November 1970. This rapid decline was followed by a steady increase to a peak of 0.093 p.p.m. by mid-March 1971. However, by June 1971, concentration of nitrate-N had again declined to background levels where it remained through September 1971. When sampling resumed in January 1972, nitrate-N was 0.175 p.p.m. and eventually reached a peak concentration of 0.310 p.p.m. by mid-March. Another peak (0.108 p.p.m.) occurred in May, but by July, nitrate-N had returned to background levels.

The nitrate-N peak that occurs immediately after urea fertilization is a result of direct application of urea to the stream (Moore 1971, Klock 1971, Malueg et al. 1972). Although the cause of this is not known, it possibly results from exchange of carbonate and bicarbonate ions for nitrate ions at anion exchange sites in the stream by mass ion effect. This would depend on rapid conversion of urea to ammonium carbonate at temperatures of 2° to 8° C. Malueg et al. found that urea pellets contained 19.33 mg./kg. of nitrate-N and concluded that this was the source of the nitrate peak that follows fertilization. Using Klock's (1971) data for total discharge and total nitrogen loss in streamflow after urea fertilization and data from Malueg et al. (1972) for nitrate-N concentration in urea fertilizer, the resultant nitrate-N concentration in streamflow was calculated. Nitrate-N concentration in streamflow from this source would be 1.8×10^{-6} p.p.m.--more than 1,000 times less than the concentrations observed in these studies. Therefore, the concentration of nitrate-N in urea fertilizer does not appear to be sufficient to account for the observed concentrations following direct application to the stream. There is a need for further study to elaborate the pathways and mechanisms involved in this rapid increase in nitrate-N following urea contamination of mountain streams.

For 1971 and 1972, the maximum observed level of nitrate-N in Falls Creek (burned, fertilized) occurred in mid-March. Peak runoff from these streams characteristically occurs between late May and mid-June.[2] Occurrence of the

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[2] Personal communication from Mr. Gran Rhodus, Wenatchee National Forest. Data furnished were for Safety Harbor and Gold Creeks which are watersheds adjacent to the study area.

nitrate-N peak before the time of maximum discharge indicates that moisture moved from the snowpack into and through the soil during the winter. It is unlikely that nitrate ions would migrate such distances in response to a concentration gradient. Haupt (1972) has observed percolation of water from the snowpack into the soil during winter months.

During the first winter after fertilization, conversion of urea-N to nitrate-N in the soil was the most likely source for nitrate-N in streamflow. Although the activity of enzymes is slowed considerably by low temperatures, urea continues to hydrolyze to ammonia at 2° C. (Broadbent et al. 1958). Conversion of ammonia-N to nitrate-N has also been shown to occur at 2° C. (Frederick 1956).

The data indicate that part of the increase in nitrate-N concentration the second year resulted from burning alone. A similar study by Tiedemann and Helvey (1973) showed that nitrate-N increased from a maximum of 0.015 p.p.m. before fire to a maximum of 0.56 p.p.m. during the second year after a severe wildfire. In the stream from a burned watershed that was fertilized with 54 kg./ha. of N as urea, the maximum nitrate-N concentration during the second year after fire was 1.47 p.p.m. Because of differences in fire intensity between Camas and Falls Creeks, the two burned watersheds, the data of the present study probably do not give a true indication of the actual increase that results from burning alone. Camas Creek (burned, unfertilized) is a small watershed (680 ha.) that had

coniferous vegetation in the upper half, and except for trees near the stream channel, supported a shrub-grass vegetation in the lower half (see footnote 2). Fire intensity in the upper half was about equally light and heavy with the exception of one small area of medium burn; the lower half of the watershed was unburned or only lightly burned. Falls Creek (burned, fertilized), in contrast, is a large (2,500 ha.) watershed that was covered mostly with coniferous vegetation. Much of this watershed received medium to heavy burn.

Cations

Total concentration of the four measured cations was substantially higher in the stream from the burned, unfertilized watershed than from either the unburned, unfertilized control or the burned, fertilized watershed (20.2 p.p.m. compared with 13.2 and 12.0 p.p.m., respectively).

Calcium was the predominant cation in all three streams, averaging 10.3 p.p.m. for the burned, unfertilized watershed and 6.5 p.p.m. for the other two watersheds (table 1). Calcium fluctuated more widely over time than any other cation, ranging from 2 to 19 p.p.m. (fig. 2). Potassium had the lowest concentration of the cations. Concentration fluctuated narrowly between 0.4 and 2.0 p.p.m. (fig. 3), and there were essentially no differences in average K concentration among streams (table 1).

Magnesium displayed different trends among streams than the other cations. Concentration was

Stream and treatment	Cation				
	Ca	Mg	Na	K	Total
	- - - - - - - Parts per million - - - - - - -				
Grade Creek, unburned and unfertilized	6.49	2.46	3.20	1.09	13.24
Camas Creek, burned and unfertilized	10.29	2.58	6.03	1.26	20.16
Falls Creek, burned and fertilized	6.51	1.49	2.96	1.04	12.00

consistently lower by about a third in the stream from the burned, fertilized watershed (1.49 p.p.m.) than in the streams from the control (2.46 p.p.m.) or the burned, unfertilized watershed (2.58 p.p.m.) (table 1, fig. 4).

The comparison among streams for Na was similar to that for Ca--average Na concentration in the stream from the burned, unfertilized watershed was nearly twice as great (6.03 p.p.m.) as in the unburned control (3.20 p.p.m.) and burned, fertilized (2.96 p.p.m.) streams (fig. 5).

Seasonal trends among streams were most evident for Mg and Na. Concentrations of these two cations in the control and burned, fertilized streams were lowest between mid-May and mid-June, the period of peak discharge (figs. 4 and 5).

In the stream from the burned, unfertilized watershed, the lowest concentrations occurred during mid-April.

Considering the mineralizing effect of fire on cations tied up in plant tissue and detritus (Ahlgren and Ahlgren 1960), it was surprising that this was not manifested by an increase in cation concentration in the stream from the burned, fertilized watershed as apparently occurred in the stream from the burned, unfertilized watershed. However, the results concur with those obtained by Johnson and Needham (1966) who also failed to detect changes in ionic composition of streams draining burned coniferous forest watersheds in California. This was attributed to an increase in runoff following fire which diluted the ion concentration, thereby
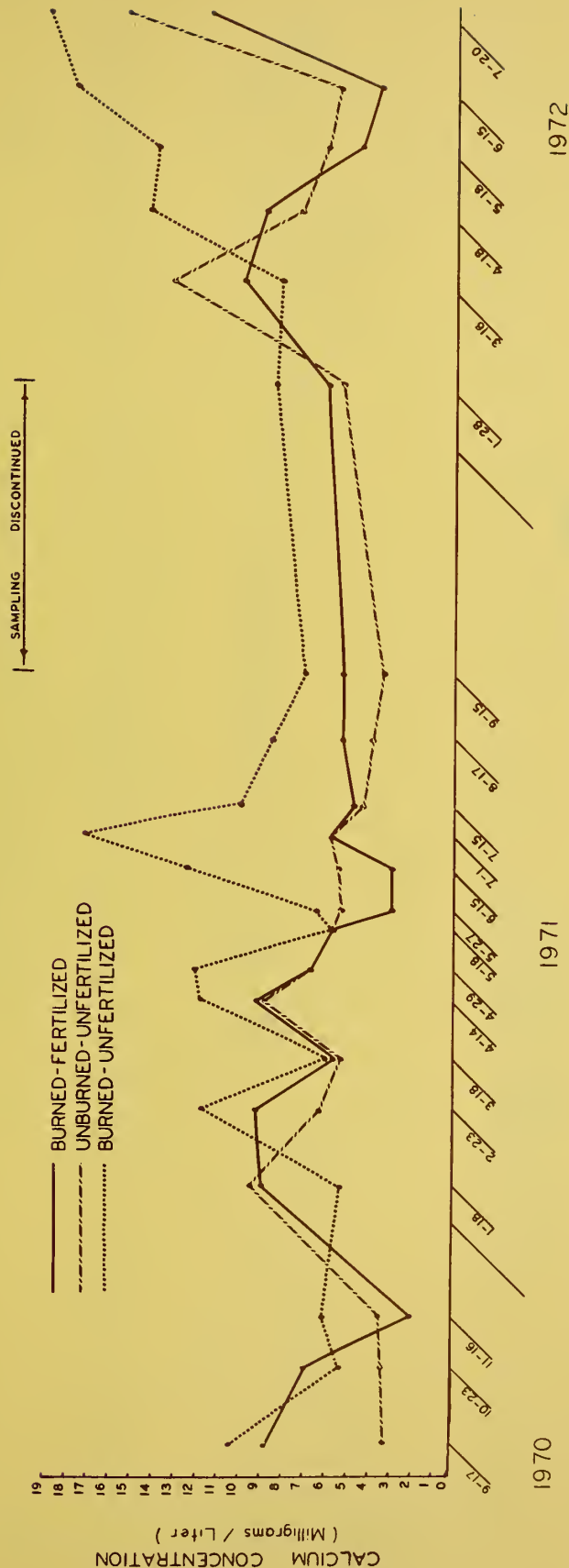
Figure 2.--Concentration of calcium in streams from unburned and unfertilized, burned and unfer-
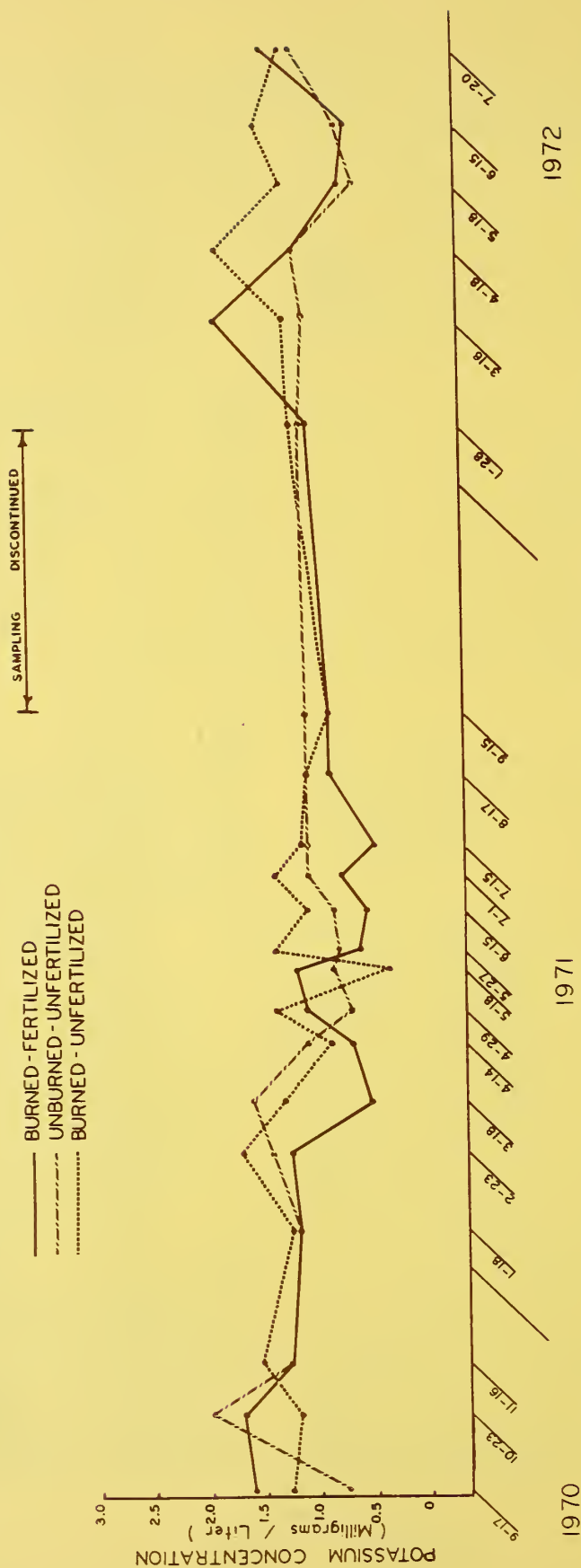tilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.

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Figure 3.—Concentration of potassium in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.

Figure 4.--Concentration of magnesium in streams from unburned and unfertilized, burned and unfer-
tilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.
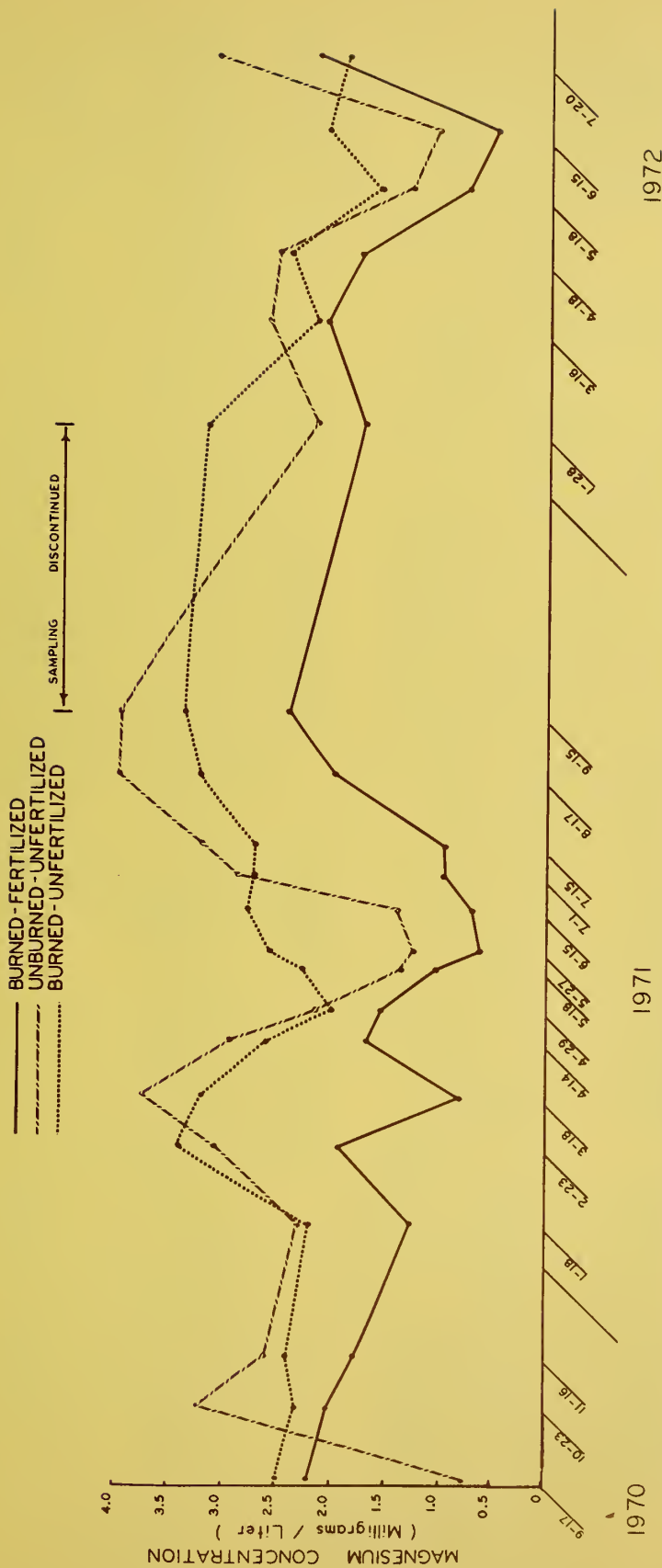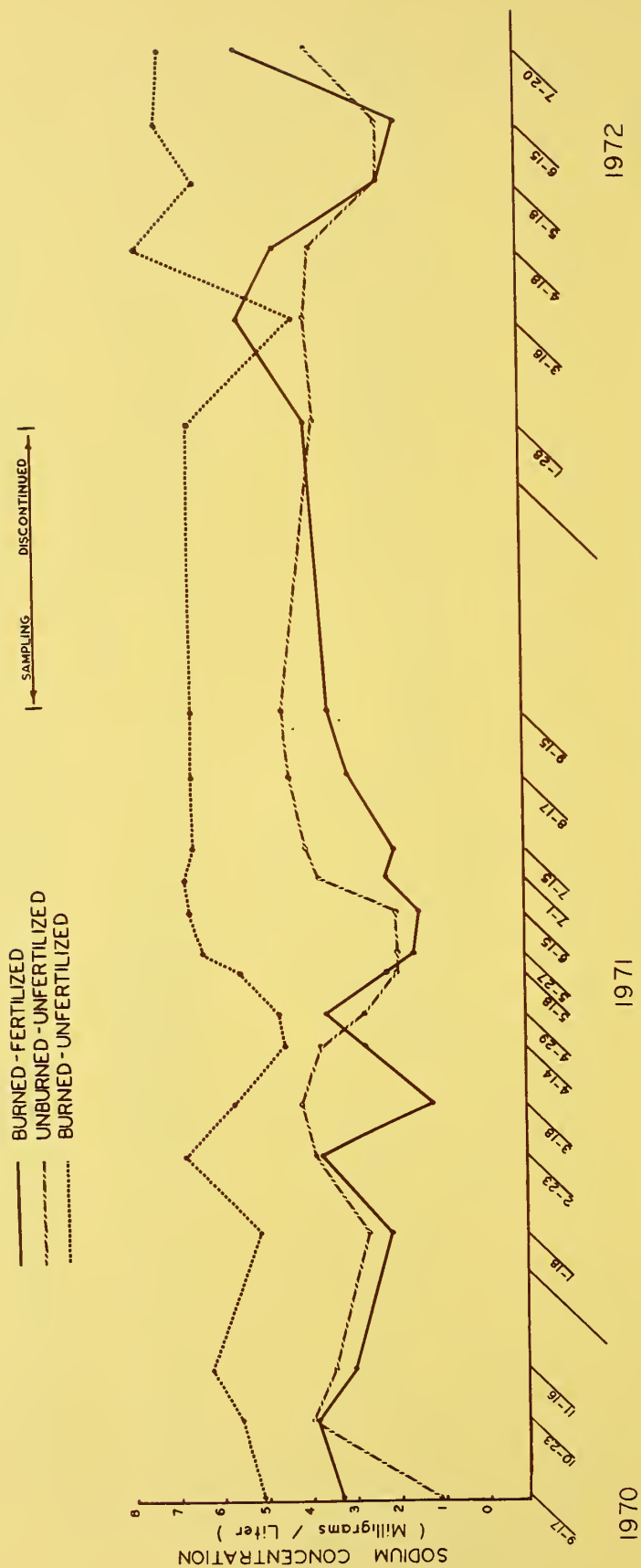
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Figure 5.--Concentration of sodium in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.

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masking true losses of ions from the watersheds. Fredriksen (1971) reached a similar conclusion in studies of ion concentration and total ion losses following clearcutting and broadcast slash burning. Studies on the Entiat Experimental Forest indicate that dilution resulting from increased runoff is an important factor to consider in assessing the impact of fire on total cation losses. Helvey (1972) observed an average increase in runoff of 3.5 inches the first year after fire from the Entiat Experimental Forest. Nutrient budget studies on the same watersheds by Tiedemann and Helvey (1973) showed that average concentrations of Ca, Mg, K, and Na during the first 2 years after fire were similar to or less than before the fire. However, because of increased runoff, total losses of the four cations increased from 19.3 to 60.6 kg./ha./yr.

Differences in cation concentration among streams in the present study can probably be related to differential increases in runoff.

Because much of the Falls Creek watershed (burned, fertilized) was in a medium to heavy burn category, it appears likely that the greatest streamflow response to the fire occurred on that watershed, thus resulting in the greatest dilution of the cation concentration. Camas Creek, because less of the watershed was burned and the burn was less severe than Falls Creek, probably had a smaller increase in runoff and less dilution of cation concentration.

The observed seasonal trends of cations probably also result from the dilution effect, since lowest concentrations coincide with peak runoff on the unburned control and burned, fertilized watersheds.

The low concentration of K in runoff presents an anomaly to its concentration at the soil surface after fire and the solubility of its carbonate salt. Grier (1972) measured concentrations of cations in ash of the burned Entiat Experimental Forest and found the ash contained 217 kg./ha. of Ca, 59 kg./ha. of Mg, 39 kg./ha. of K, and 7 kg./ha. of Na. Of these amounts, 31 percent of the Ca, 80 percent of the Mg, 84 percent of the K, and 92 percent of the Na were transferred to the soil in 670 millimeters of flow. Since potassium carbonate is a highly soluble salt and K is a more mobile ion than either Ca or Mg, the ratio of concentration in runoff to concentration at the surface would be expected to be similar to the ratio for Ca and Mg. Grier (1972) speculates that K concentration is not proportional to the other elements in water draining the upper 36 cm. of profile because of fixation of K in interlamellar sites of vermiculite clays.

Total Alkalinity, Electrical Conductivity, and Hydrogen Ion Activity

Total alkalinity, which represents the concentration of carbonate and bicarbonate ions and other anions in the stream, maintained a narrow range between 0.5 and 2.2 milliequivalents per liter and showed the same general trends

among streams and sampling dates as the concentration of cations (fig. 6). Total alkalinity was similar in Grade (control) and Camas (burned, unfertilized) Creeks and lowest in Falls Creek (burned, fertilized). Seasonally, the lowest levels of alkalinity coincided with peak discharge.

Concurrence of trends of total alkalinity with those of cations was not surprising since it has been shown that the bicarbonate ion is primarily responsible for cation transport within the soil (McColl and Cole 1968). Bicarbonate probably accounts for 80 to 90 percent of total alkalinity observed in this study since pH is between 7 and 8 (Golterman and Clymo 1969, Hem 1970). The data show that there is no shortage of bicarbonate ions after fire. If anything, the supply is greater; but because of dilution effects, the concentration remains at a level similar to that in the control stream. Increased activity of micro-organisms (Ahlgren and Ahlgren 1960) and rapid conversion of oxides of metals to carbonates apparently replace root respiration by higher plants as a source of bicarbonate ions.

Electrical conductivity in the unburned control and burned, unfertilized streams fluctuated widely during the first year, but there were no consistent differences between the two streams to indicate that burning had any effect on ionic concentration of the stream water (fig. 7). Seasonal changes during 1971 on these two streams, however, were striking, with a sharp rise in the early spring to over 225 micromho per centimeter (μmho/cm.) followed by a decline to less than 90 μmho/cm. in April at the start of spring runoff. In July, conductivity rose above 200 μmho/cm. again and remained at that level until the end of sampling. Electrical conductivity on Falls Creek (burned, fertilized) was a distinct contrast, remaining below 105 μmho/cm. until August 1971. During 1972, electrical conductivity was more uniform and similar among the three streams with the lowest values occurring between mid-May and mid-June during peak discharge. Electrical conductivity and cation trends were similar because the ability of streamwater to conduct an electric current is directly related to the quantity and degree of dissociation of solutes (Hem 1970).

Hydrogen ion activity (pH) fluctuated between 7.1 and 9.5 during the sampling period from September 1970 through April 1971 with no apparent trends among streams or sample dates (fig. 8). During the sample period from April 1971 through July 1972, pH was generally lowest in the stream from the burned, fertilized watershed. During this period, pH reached the lowest levels in mid-June of 1971 and again in mid-April of 1972.

Except for the first two sample occasions in the stream from the burned, fertilized watershed, pH was within the range Hem (1970) describes for most natural waters (6.0 to 8.5).

The high pH value (9.5) observed October 23, 1970, just 2 days after fertilization, appears linked
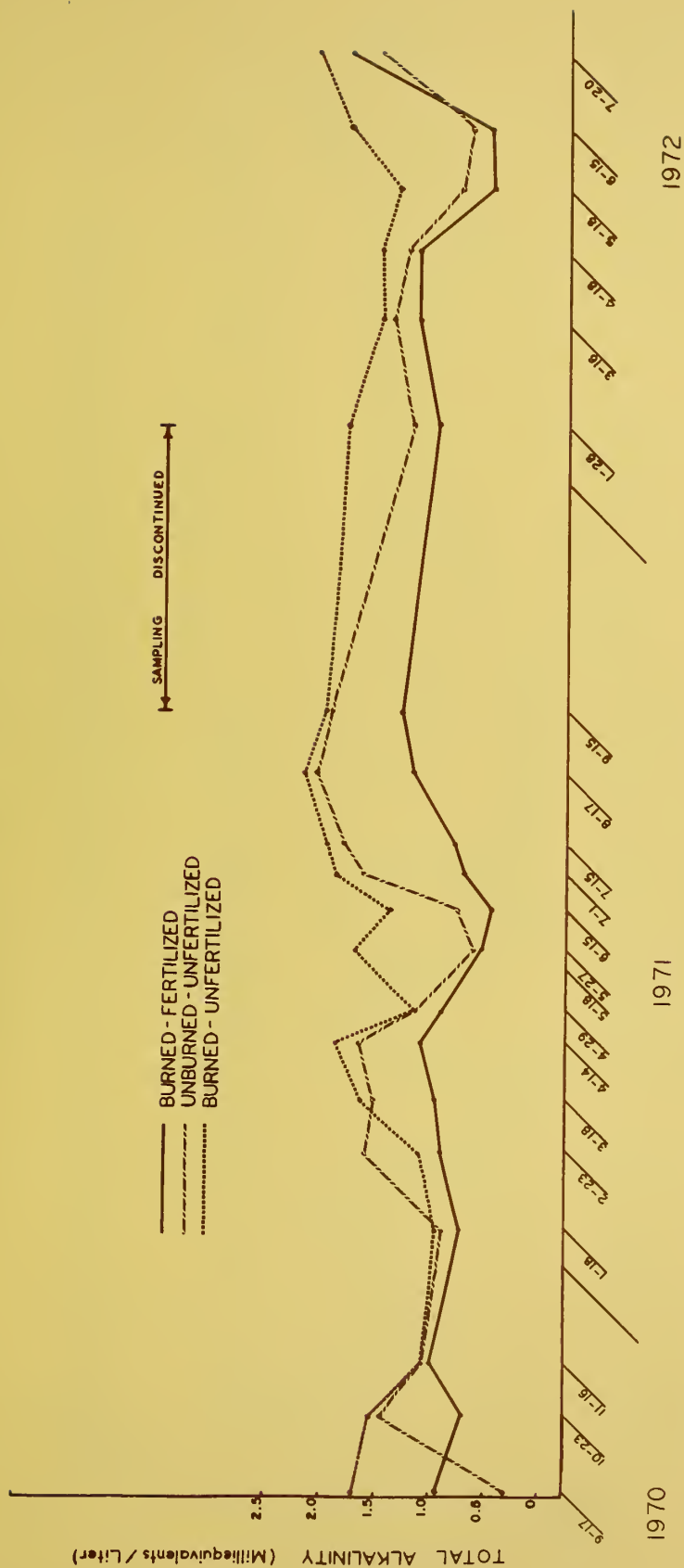
Figure 6.--Total alkalinity in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.
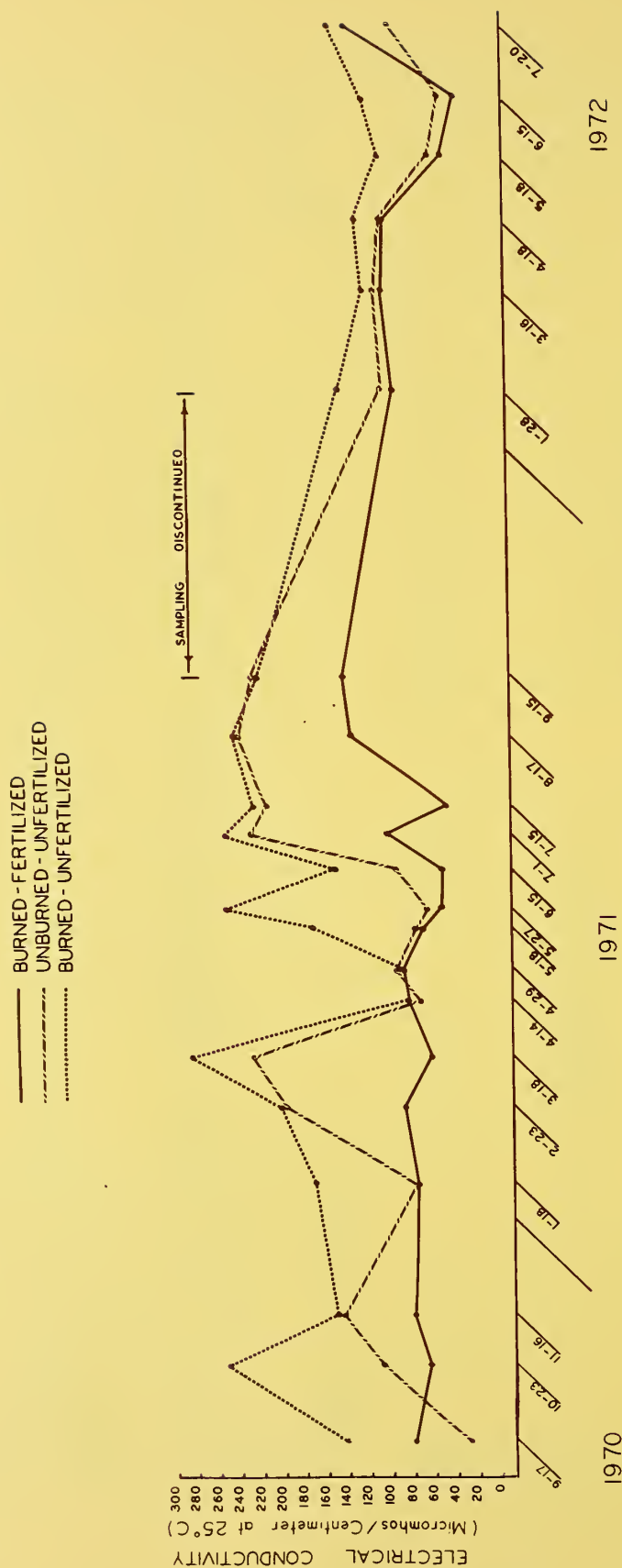
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Figure 7.--Electrical conductivity in streams from unburned and unfertilized, burned and unfer-
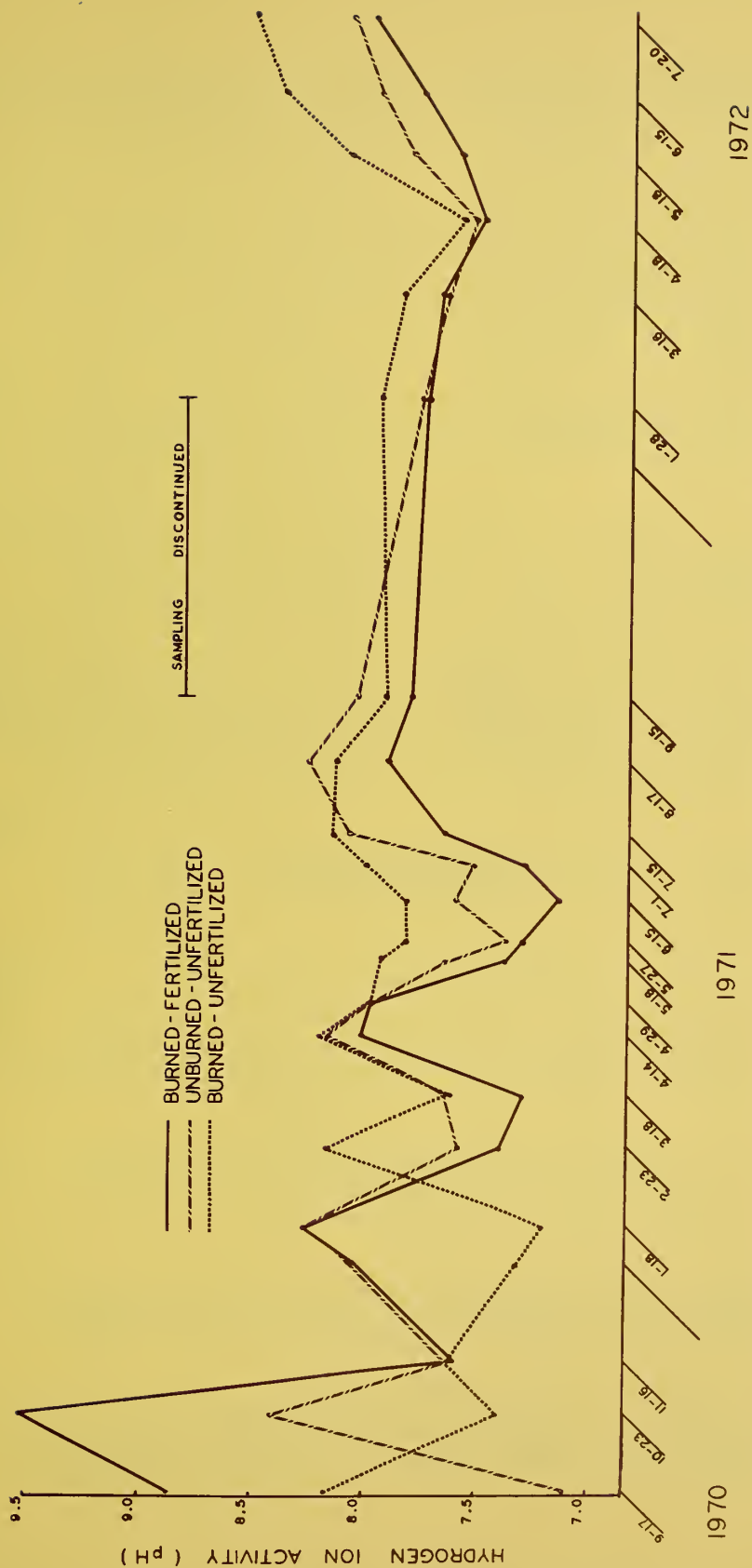tilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.

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Figure 8.--*Hydrogen ion activity (pH) in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

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to direct application of urea to the stream. Hydrolysis of urea causes a temporary increase in soil pH (Broadbent et al. 1958). However, since the pH value was 8.9 on the sample date just prior to fertilization, the high values observed are more likely the result of instrument error and accidental freezing of a few of the early samples before analysis. Separate laboratory tests by the author showed that freezing a sample causes an increase in pH units of 0.5 to 1.00.

CONCLUSIONS

The quality of water for municipal use from watersheds involved in the fire does not appear to be threatened by either burning or urea fertilization during the first and second year after these treatments. Even though urea fertilization after fire at 78 kg./ha. apparently caused immediate and protracted increases in nitrate-N levels, the maximum observed level of 0.31 p.p.m. poses no hazard. This value is 30 times less than the proposed permissible level. Nitrate-N losses from the burned, unfertilized and burned, fertilized watersheds are probably less than those observed by Tiedemann and Helvey (1973). Nitrate-N losses on a burned watershed of the Entiat Experimental Forest increased from 0.008 kg./ha./yr. before fire to 1.92 kg./ha./yr. the second year after fire. On a watershed that was burned and fertilized with 54 kg./ha. of urea, losses increased from 0.0002 to 3.28 kg./ha./yr. Thus, it is not likely that losses of nitrate-N in streamflow are substantial enough to affect future productivity of these ecosystems.

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